

Climate Data Guide
Modern Era Retrospective analysis for Research and Applications, version 2 (MERRA-2)
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Summary

The Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2) is a global atmospheric reanalysis produced by the NASA Global Modeling and Assimilation Office (GMAO). It spans the satellite observing era from 1980 to the present. The goals of MERRA-2 are to provide a regularly-gridded, homogeneous record of the global atmosphere, and to incorporate additional aspects of the climate system including trace gas constituents (stratospheric ozone), and improved land surface representation, and cryospheric processes. MERRA-2 is also the first satellite-era global reanalysis to assimilate space-based observations of aerosols and represent their interactions with other physical processes in the climate system. The inclusion of these additional components are consistent with the overall objectives of an Integrated Earth System Analysis (IESA).

MERRA-2 is intended to replace the original MERRA product, and reflects recent advances in atmospheric modeling and data assimilation. Modern hyperspectral radiance and microwave observations, along with GPS-Radio Occultation and NASA ozone datasets are now assimilated in MERRA-2. Much of the structure of the data files remains the same in MERRA-2. While the original MERRA data format was HDF-EOS, the MERRA-2 supplied binary data format is now NetCDF4 (with lossy compression to save space).

Expert Guidance

MERRA-2 (Gelaro et al. 2017) is composed of the Goddard Earth Observing System Atmospheric Data Assimilation System (GEOS ADAS), which incorporates the Global Statistical Interpolation (GSI) analysis scheme of Wu et al. (2002). The system utilizes a revised version of the GEOS global atmospheric model (Molod et al., 2014). A fundamental motive for replacing MERRA with MERRA-2 is that MERRA (c. 2008 vintage) is not capable of assimilating important new data types, and the aging and failure of older satellite instruments greatly reduced the data volume available for assimilation for the earlier reanalysis. MERRA-2's GEOS system (version 5.12.4) is able to assimilate data from the newer microwave instruments and from hyperspectral infrared radiance instruments.

While coarse-resolution data sets were used to conserve data volume in MERRA, all output data collections from MERRA-2 are provided on the same global grid ($\frac{1}{2}^\circ$ latitude \times $\frac{5}{8}^\circ$ longitude). The GEOS model used in MERRA-2 performs computations on a cubed-sphere grid

that allows for a better representation of dynamical processes in high latitudes. The distributed data collections are spatially interpolated to the latitude-longitude grid, for the convenience of users. There are no changes in the vertical grids used: variables are provided on either the native model vertical grid (at 72 hybrid-sigma layers or 73 edges), or interpolated to 42 standard pressure levels.

There is a fundamental change between MERRA and MERRA-2 over land surfaces. Soil moisture in MERRA-2 is initialized using a separate observation-based precipitation product (variable *PRECTOTCORR* in “*flx*” collections). This approach improves the representation of land surface properties and runoff, and is similar to the soil moisture initialization scheme developed for MERRA-Land (Reichle et al., 2011; Reichle, 2012; Reichle and Liu, 2014). The forcing precipitation is primarily based on gauge observations at low and midlatitudes, and gradually tapers to the MERRA-2 modeled precipitation over a zonal range from 42.5° to 62.5° latitude. The forcing precipitation is entirely composed of the MERRA-2 modeled precipitation poleward of 62.5°. Due to gauge scarcity, the NOAA CPC Merged Analysis of Precipitation (CMAP) gauge-satellite product is substituted for the soil moisture initialization over Africa (see Reichle et al 2017). The use of a separate precipitation product for soil moisture initialization affects mass balance, as the difference between the observation-based and model-generated precipitation affects the water budget when the land and atmosphere budgets are combined.

The incorporation of satellite-observed aerosols in MERRA-2 is based on the “MERRAero” off-line product that was produced using meteorological fields from the original MERRA. MERRA-2 aerosol variables are included in additional file collections, which use the tags “*aer*”, “*adg*”, and “*gas*” in their file names, similarly to the MERRAero data file (da Silva et al., 2015). MERRA-2 aerosol assimilation is documented by Randles et al (2016). Reflecting the broader scope of the assimilation system, there are several other new file collections. MERRA-2 includes a mass balance over glaciated land surfaces including Greenland and Antarctica, which is written in the GLC collection. These variables reflect an updated representation of processes over glaciated land surfaces which include fractional snow cover, meltwater percolation and refreezing, runoff, a prognostic surface albedo, and the vertical conduction of heat within the glacier surface (Cullather et al., 2014). Several surface variables have additional daily statistics written in a separate variable collection called statD. This includes the maximum and minimum daily two-meter temperature, captured at the model time step, between 00:00 UTC and 23:59 UTC every day. The GEOS model also includes the Observations Simulator Package from the Cloud Feedback Model Intercomparison Program (CFMIP COSP). COSP output for ISCCP and MODIS is provided in the CSP collection.

Questions regarding MERRA-2 science, modeling and data assimilation should be sent to: merra-questions@lists.nasa.gov.

Information on MERRA-2 data files can be found in Bosilovich et al. (2016), including information on how to cite the data itself where all data collections have a DOI. Also, the MERRA-2 budget equations are outline there.

What are the key strengths of this data set?

GMAO reanalyses allow for

- Analysis increment system provides hourly data
- Finite-volume representation of topography (not spectral)
- Access to analysis increments for budget computations

The MERRA-2 system:

- Incorporates observations from more recent satellite instruments
- More consistent time series using global mass balance constraint
- Observation corrected precipitation forcing for the land surface
- Inclusion of stratospheric ozone products
- Use of assimilated interactive aerosols and observed time varying emissions
- Improved estimates of surface mass balance and surface temperatures over ice sheets
- Use of daily sea ice and SST fields (rather than weekly in the original MERRA)

What are the key weaknesses of this data set?

- Sea ice and SST boundary forcing fields contain discontinuities that affect certain time series analysis (Bosilovich et al. 2015, Section 8):
 - AMIP II boundary fields (Taylor et al., 2000), 1980 - 1981
 - Reynolds et al. (2007), 1982 - March 2006
 - OSTIA, April 2006 - present
- Several abrupt changes in local sea ice cover, perhaps associated with satellite data quality, have been noted:
 - 12/31/1981 - 01/01/1982, Southern Hemis.
 - 03/07/2007 - 03/09/2007, NH, SH
 - 10/04/2009 - 10/05/2009, SH
 - 04/23/2012 - 04/24/2012, SH
 - 01/19/2013 - 01/20/2013, NH
 - 08/13/2013 - 08/14/2013, SH
 - 02/20/2014 - 02/21/2014, NH
 - 05/10/2014 - 05/11/2014, NH, SH
 - 06/30/2015 - 07/01/2015, NH, SH
 - 09/15/2015 - 09/16/2015, SH
 - 10/13/2015, 10/15/2015, SH
 - 04/06/2016 - 04/11/2016, NH
- Regional discontinuities associated with major observing system variations do occur

- Reanalysis divided into 4 streams (with breaks occurring at 1990-91, 2000-2001, and 2010-2011), which produce discontinuities for deep soil layers
- Precipitation is thought to be too large over polar oceans, and is excessive over high topography in tropical latitudes
- TOA net global energy is too low in the 2000s owing to too much reflected SW radiation; before that is a downward trend in reflected SW as more water vapor observations are assimilated; regionally this is dominated by the SH storm track in DJF
- Does not directly assimilate observed 2m air temperature

Meta Data

Years of Record

1980/01 to present (ongoing)

Formats

NetCDF-4 (Can be converted to HDF at data access)

Timestep

1-hourly | 3-hourly | 6-hourly | Daily | Monthly | Monthly Diurnal

Data Time Period Extended?

The system is producing present data for the foreseeable future

Domain

[Global](#)

Spatial Resolution

$\frac{1}{2}^{\circ}$ latitude by $\frac{5}{8}^{\circ}$ longitude by 72 model levels (also interpolated to 42 pressure levels)

Ocean or Land

Land is interactive, and includes observation corrected precipitation forcing. SSTs and sea ice are prescribed.

Missing Data Flag

Some ocean regions in land files include missing data. Some pressure level data where $P(\text{level}) > P_{\text{surf}}$ are undefined.

Data Assimilation Method

3DVAR

Model Resolution used to create reanalysis

Cubed sphere grid, stored at $\frac{1}{2}^\circ$ latitude by $\frac{5}{8}^\circ$ longitude by 72 model levels (also interpolated to 42 pressure levels)

Model Vintage (reanalysis)

2014

Input Data

Most in-situ and satellite data used in numerical weather forecasting, including satellite radiances

McCarty, W., L. Coy, R. Gelaro, A. Huang, D. Merkova, E. B. Smith, M. Sienkiewicz, and K. Wargan, 2016: MERRA-2 input observations: Summary and initial assessment. Technical Report Series on Global Modeling and Data Assimilation, Vol. 46, NASA Tech. Rep. NASA/TM–2016–104606, 61 pp. [Available online at <https://gmao.gsfc.nasa.gov/pubs/docs/McCarty885.pdf>.]

Earth system components and main variables

Assimilated **Aerosols**, [Atmosphere](#), [Air Temperature](#), [Geopotential Height](#), [Precipitable water](#),

Get Data

MERRA-2 data are available at [MDISC](#), managed by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

[Web-based Reanalysis Intercomparison Tools \(WRIT\)](#) — Allows users to quickly analyze and intercompare multiple contemporary reanalyses data.

Collaborative REAnalysis Technical Environment (CREATE) — Incorporating a multitude of reanalyses together with observation and climate models:

<https://esgf.nccs.nasa.gov/projects/create-ip/>

<http://cds-cv.nccs.nasa.gov/CREATE-V/>

References

Project overview paper:

Gelaro, R., W. McCarty, M.J. Suárez, R. Todling, A. Molod, L. Takacs, C.A. Randles, A. Darmenov, M.G. Bosilovich, R. Reichle, K. Wargan, L. Coy, R. Cullather, C. Draper, S. Akella, V. Buchard, A. Conaty, A.M. da Silva, W. Gu, G. Kim, R. Koster, R. Lucchesi, D. Merkova, J.E. Nielsen, G. Partyka, S. Pawson, W. Putman, M. Rienecker, S.D. Schubert, M. Sienkiewicz, and

B. Zhao, 2017: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). *J. Climate*, 30, 5419–5454, <https://doi.org/10.1175/JCLI-D-16-0758.1>

Technical memoranda related to the system:

<https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/docs/>

MERRA-2 AMS Special collection, a diverse set of initial research papers:

<http://journals.ametsoc.org/topic/merra-2>

GMAO's MERRA-2 Reference List:

<https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/pubs/>

Cited on Climate Data Guide:

Bosilovich, M. G., R. Lucchesi, and M. Suarez, 2016: MERRA-2: File Specification. GMAO Office Note No. 9 (Version 1.1), 73 pp, available from

http://gmao.gsfc.nasa.gov/pubs/office_notes.

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Reichle, R., Q. Liu, R. Koster, C. Draper, S. Mahanama, and G. Partyka, 2017: Land surface precipitation in MERRA-2. *J. Climate*, **30**(5), 1643-1664, doi:10.1175/JCLI-D-16-0570.1

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Takacs, L. L., M. Suarez, and R. Todling, 2015: Maintaining Atmospheric Mass and Water Balance Within Reanalysis. NASA/TM–2014-104606, Vol. 37. <http://gmao.gsfc.nasa.gov/pubs/docs/Takacs737.pdf>

Taylor, K.E., D. Williamson, and F. Zwiers, 2000: The Sea Surface Temperature and Sea-Ice Concentration Boundary Conditions for AMIP II Simulations. PCMDI Report No. 60, 24 p. [Available from DOE Office of Scientific and Technical Information, Oak Ridge, TN].

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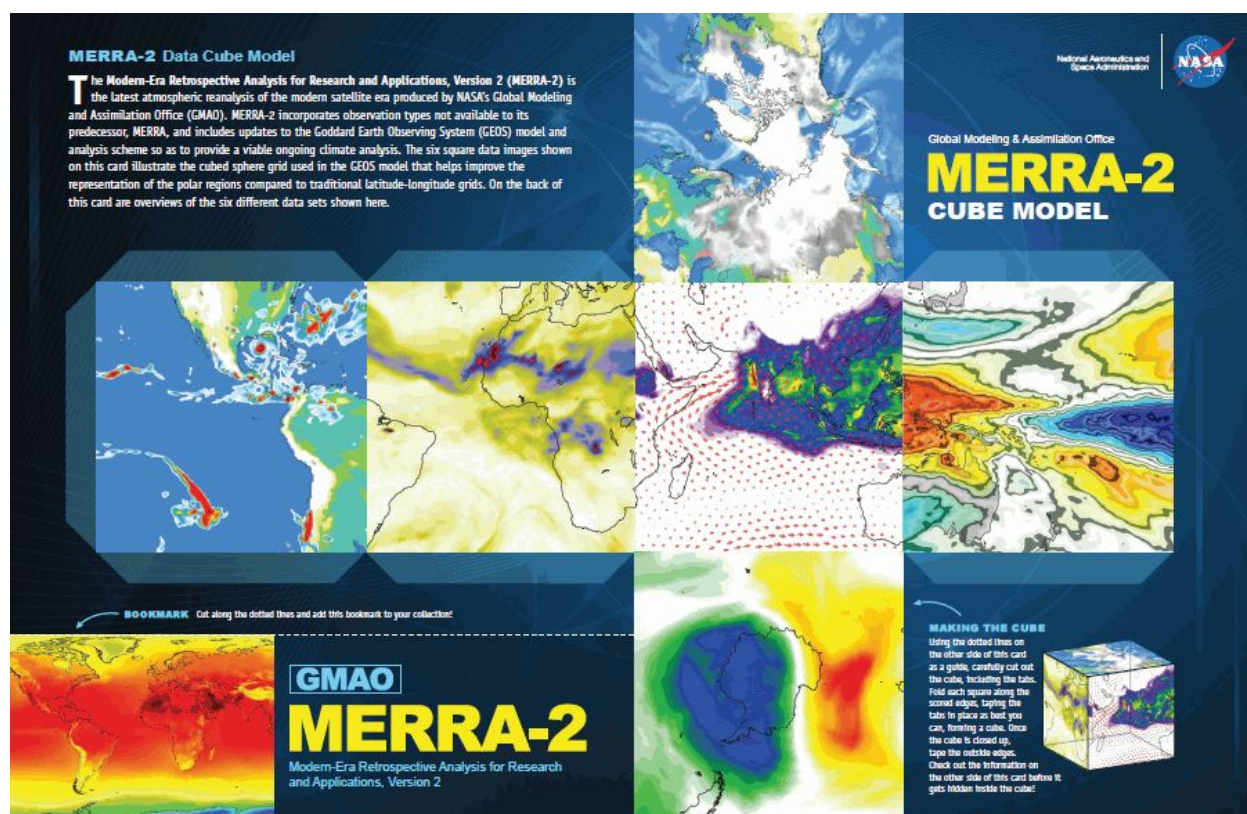


Fig. 1. MERRA-2 infographic.

Table 4-1 Energy budget terms from the NEWS integrative project (L'Ecuyer et al. 2015), which includes the original collected data and a balanced budget with uncertainties (e), alongside MERRA-2 and MERRA for the period of 2000-2010. Not included in the table are the atmospheric heating rates from MERRA and MERRA-2 analysis increments, which are 6.8 and -2.4 Wm^{-2} , respectively. Units are Wm^{-2} .

Budget Term		Original	e	Constrained	e	MERRA-2	MERRA
Incoming Solar	F	340 ± 0.5		340 ± 0.5		340	341
Outgoing Shortwave	OSR	100 ± 5.0		98 ± 2.0		106	100
Outgoing Longwave	OLR	238 ± 2.0		239 ± 2.0		238	242
Downwelling LW at SFC	LW↓sfc	344 ± 7.0		339 ± 4.0		332	331
Downwelling SW at SFC	SW↓sfc	190 ± 6.0		187 ± 3.0		186	193
Surface Emitted	LW↑sfc	398 ± 6.0		400 ± 4.0		394	394
Surface Reflected	SW↑sfc	22 ± 2.0		22 ± 1.0		23	24
Sensible Heating	SH	21 ± 5.0		23 ± 3.0		19	18
Precipitation LH	LvP	77 ± 7.0		80 ± 4.0		87	81
Evaporation LH	LvE	75 ± 7.0		80 ± 4.0		86	76
Surface Heat Storage	Net Abs.	0.6 ± 0.4		0.91		-4.5	11.4

Figure 2 Terms of the MERRA-2 energy budget compared with MERRA and merged observed satellite data (excerpt from Bosilovich et al 2016).

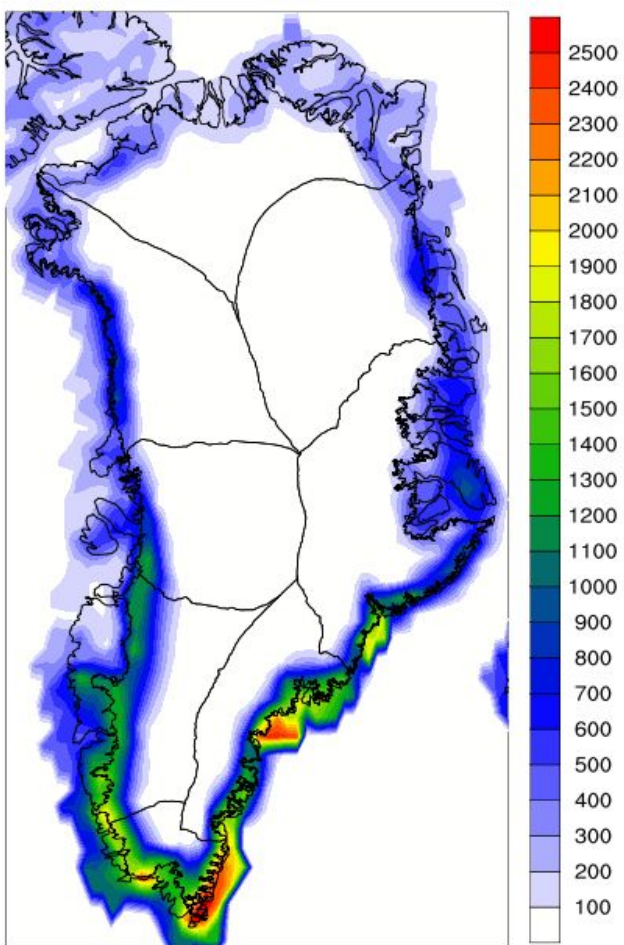


Figure 3. MERRA-2 1980-2016 average Greenland Ice Sheet annual runoff, in mm w.e. yr⁻¹.